64-25

State of California
Department of Public Works
Division of Highways
Materials and Research Department

August 17, 1964

Proj. W. O. 61245-R

Mr. John L. Beaton
Materials and Research Engineer
Materials and Research Department
Sacramento, California

Dear Mr. Beaton:

Submitted for your consideration is:

A REPORT ON

VEHICLE RESPONSE TO PAVEMENTS

Study made by . . . . . Structural Materials Section

Under direction of . . . . . John L. Beaton and Eric F. Nordlin

Work supervised by . . . . . J. E. Barton and W. Chow

Report prepared by . . . . . W. Chow

Very truly yours,

Eric F. Nordlin

Eric F. Nordlin
Assistant Materials and Research
Engineer - Structural

..:mw
Attach.

VEHICLE RESPONSE TO PAVEMENTS

A memorandum dated October 18, 1960, from Mr. M. Harris to Mr. F. N. Hveem requested that the laboratory evaluate effectiveness of variable concrete joint spacings over regular 15' joint spacings "to reduce the undesirable effect on a vehicle and occupants of periodic irregularity in the profile of a concrete pavement with uniformly spaced joints". A location list of 13, 17, 14, 16 feet variable joint spacings in PCC pavements was attached; i.e., III-Yol-90,6-A,B, Win, D; X-Sol-90-A; VII-LA-2-LA; VI-Fre,Mod-4-C,A, and VI-Ker-D,F. A memo dated November 9, 1960, from Mr. F. N. Hveem to Mr. M. Harris stated a vehicle would have to be obtained that manifested "the objectionable response to our normal joint spacings". Heresay indicated that a General Motors car was the vehicle.

On March 22, 1961, Mr. Hveem received a letter from Mr. V. D. Polhemus, Engineer-in-charge, Structures and Suspension Development, General Motors Corporation, setting up a meeting to observe "freeway hop" on our freeways early in the summer.

Research Project 32/55-R-6245 (now R-61245) was set up on April 19, 1961, to develop instruments to measure vehicle response to our PCC pavements and a secondary objective of developing a "Pavement Comfort Index".

A 1958 Chevrolet 4-door sedan, State owned, was selected as the pavement response vehicle because of its availability and it being a GM product. Accelerometers were mounted on the front, center, and rear car frame. Accelerometer outputs were fed into suitable electronic conditioning equipment and recorded on an oscillograph (Figure 1). All of the instrumentation was carried and mounted in the test vehicle. The instrumentation weighed approximately 500 lbs.

Vehicle responses to PCC pavement test runs were made in the vicinity of Dixon-Davis, Woodland River road, and a new stretch of asphalt pavement on Stockton Boulevard. Test runs were made at 45, 55, and 65 mph and also with the shocks inactivated for comparisons. Results indicated that the location of the accelerometers on the frame did not pick up vehicle "hop" motions, if any, or were in the wrong locations to pick them up. Subjective observations confirmed that the Chevrolet did not have a periodic "hop" over the search range speed of 45, 55, and 65 mph. A total of 16 runs was made in the above series of tests.

In the next approach an additional accelerometer was mounted on the supporting frame of the right front wheel. The thought behind this was that the wheel would "hop" according to the spacing of the PCC transverse joints. The same highway locations were rerun with the various speeds and with and without the shocks activated. Wheel "hop", if any present, was completely masked out by the wheel runout, wheel rotational and unsprung wheel frequencies.

The next approach was to measure the differential accelerations between the front chassis and the front wheels in hopes of

finding some correlation between pavement joints and differential movements between chassis and wheel. An additional accelerometer was mounted directly beneath the driver's seat in hopes that "hop" would transmit through the car floor into the car seat. This method also did not indicate any "hop" due to the masking effects of the car's springs and unsprung frequencies. Figures 2 through 6 show some of the various accelerometer locations tried and typical curves obtained.

The next logical step was to actually measure a person's response to pavement roughness or car "hop". Accelerometers were left in the same car locations and one additional accelerometer was attached to a person's chest area. See Figure 7. Results were not encouraging since any tilt, movement, or swaying of the person would mask out the desired information. It was thought that by moving the chest accelerometer to the shoulders, Figure 8, results would be improved. However, much was still to be desired with respect to measuring pavement roughness or car response.

Mr. Hveem then came up with the premise that discomfort or lack of road roughness can be measured by the differential accelerations between a person's top and bottom spine. Accordingly, accelerometers were mounted in the vicinity of the neck, Figure 9, and on the top of the car seat directly behind the person's posterior. Again various test runs were made at various speeds and over smooth and rough asphalt pavements, PCC pavements with 15' joints, and random joints with no conclusive results.

Results left much to be desired because of masking effects of various car frequencies and the unrepeatable performance of individuals required to sit as motionless as possible during several miles of test runs.

During this period of investigation a 50 lb. weight, Figure 10, was also instrumented with an accelerometer and placed at various locations on the car floor. Also, car motion noises were thought to contribute to discomfort so that interior car noises were also recorded. Typical records obtained during this phase of the investigation are shown on Figure 11. Car noises and the 50 lb. weight did not provide significant information.

Three other makes of cars were also used during this period (August through September 1961) as test vehicles: a 1948 Buick, a 1959 Dodge, and a 1960 Plymouth. For comparisons the same roads were run at the same various speeds. No direct comparisons could be made between the three test vehicles except that they rode differently on the same road and manifested no "hop" problem.

During this period it was decided to try to correlate and compare the shape of the test records with our profilograph records. A fifth wheel, Figure 11a, was built that drove the oscillograph record paper at a constant 1" = 25 foot of pavement traveled. Attachment of the fifth wheel was made so that it could be readily attached to any car bumper.

This study indicated that the 1948 Chevrolet, 1948 Buick, 1960 Plymouth, and the 1959 Dodge all did not exhibit any so-called "freeway hop" nor was the secondary objective of obtaining a "road profile comfort index" accomplished. Only conclusions reached were that all four cars exhibited different "road riding characteristics". Recordings of several cars at 55 mph are listed here for the record and also included for the files. Comparison of these recordings with profilograph records taken over the same pavements indicated that the differential movements between the car chassis and the right front wheel recordings had a similar shape to the profilograph recordings.

ROAD RECORDINGS FOR COMPARISONS

(at 55 mph)

Roseville Hwy. 40 (West Bound Outside Lane)

Sta. 474 + 85 - 448 + 66 - 419 + 55

Sept. 6, 1961 1960 Plymouth (Run #230)
Sept. 14, 1961 1958 Chevrolet (Run #241)
(Run #250 1959 Buick can be compared with above records)

Antioch Hwy. 24 (East Bound Inside Lane)

Sta. 311 + 00 to 379 + 00

Sept. 7, 1961 1960 Plymouth (Run #237)
Sept. 15, 1961 1958 Chevrolet (Run #246)
(Run #266 1959 Buick can be compared with above records)

Healdsburg Hwy. 101 (North Bound Outside Lane)

Sta. 758 + 03 to 915 + 31 (total 3 miles)

July 25, 1961 1958 Chevrolet (Run #119)
NOTE: 1960 Plymouth did not run on this road. Can be compared with 1959 Buick Run #258.

Winters Hwy. 99 (North Bound Outside Lane)

Sta. A3 540 + 00 to B4 115 + 00

July 21, 1961 1958 Chevrolet (Run #109)
NOTE: 1960 Plymouth did not run on this road. Can be compared with 1959 Buick Run #276.

During September a 1959 Buick sedan, Figure 12, was loaned to us by the GM Corp. for our use in evaluating and measuring its vehicle "hop".

This car was instrumented with the previcus setup of accelerometers on subjects' neck and posterior, Figure 13, sound level recording device, the instrumented 50 lb. weight, a differential acceleration recording device between chassis and wheel, and a new one-man jury indicator. At a later date the differential

acceleration recording device between the chassis and wheel was removed and a strain gaged cantilever beam, Figure 14, measuring differential movements was installed. This was a much simpler and improved measuring setup.

A portion of the record run at Antioch with the Buick is included for the record, Figure 15. Note the pronounced 15 foot joints showing up on the differential movements between the chassis and wheel recordings. Figure 16 shows views of instrumentation in the 1959 Buick.

During October 1961, the 1959 Buick and a 1961 Buick, also on loan from GM, was extensively road tested in six Los Angeles areas. Four of the areas are shown on Figure 17. Figures 18 and 19 are included as a record of the runs that were made. In general, the two Buicks were very smooth riding over "rough" roads but exhibited a pronounced "hop" over PCC pavement joints. It was also noted that extra weights in the trunk, i.e., spare tire or fifth wheel, would aggravate the "hop" problem.

Through analyzation of all records of all cars to date by various methods, i.e., integrating areas under the recorded curves, counting heights of curves, counting pips, counting pips above and below certain magnitudes, matching and comparison with profilograph records, indicated that instrumentation methods to date were not measuring pavement roughness or comfort.

All of the previous instrumentation approach was now dropped except the jury rating and the differential movements between wheel and chassis.

The jury rating was expanded to three jurists, each rating the smoothness of a predetermined stretch of pavement at the same time in the same car. Many miles of road were jury-rated in this manner. This method was finally dropped because of the wide variance as to how "smooth" or "rough" a smooth or rough road should be and various other physiciological side problems involved, i.e., fatigue, hearing, etc. In addition, if a fixed numerical number was assigned to a "smooth" and "rough" road and each jurist was indoctrinated in such a "number", each jurist would only be confirming each other's opinions.

Therefore, the next step was to determine if a mechanical dummy could be substituted for the three jurists and without the various physciological side problems, i.e., fatigue, hearing, etc. involved. The differential movements between the wheel and chassis were retained throughout the rest of this project because of the similarity of the shape of the curve to the profilograph records.

To acquire parameters to build the mechanical dummy, an investigation was first carried out to determine a person's response to simulated vertical car motions. A Ford Ranchwagon car seat was placed on a vertical shake table, Figure 20, and numerous persons' response to various vibratory motions investigated. Human response was measured by accelerometers located at shoulder and tailbone as

previously developed. A large range of body types was chosen for this investigation. Results indicated that no two persons responded alike and even "similar" body types responded differently. A typical body type with typical response simply did not exist. Figures 20A and 20B are included for the record to show the response variations recorded on various body types.

Parameters to build the mechanical dummy with were arbitrarily chosen from the above investigation. Building of the dummy was a trial and error method with numerous trial runs, both on the highway and on the shake table, to determine its response. Figures 21 through 25 show some of the development stages in the dummy evolution.

A large amount of time and effort went into developing the mechanical dummy to simulate a human torso but with no avail. The main unsolved problems were:

1. The dummy exhibited a resonant frequency which was not present in a human torso. Many combinations of pads and springs were tried to eliminate it. The most successful but not successful enough were Ensolite rubber-like sheets.

2. Output of the dummy would not repeat from "sittings" to the same "sittings" on the vehicle seat.

3. The dummy was just not human enough to pick up the varied responses that aggravate humans.

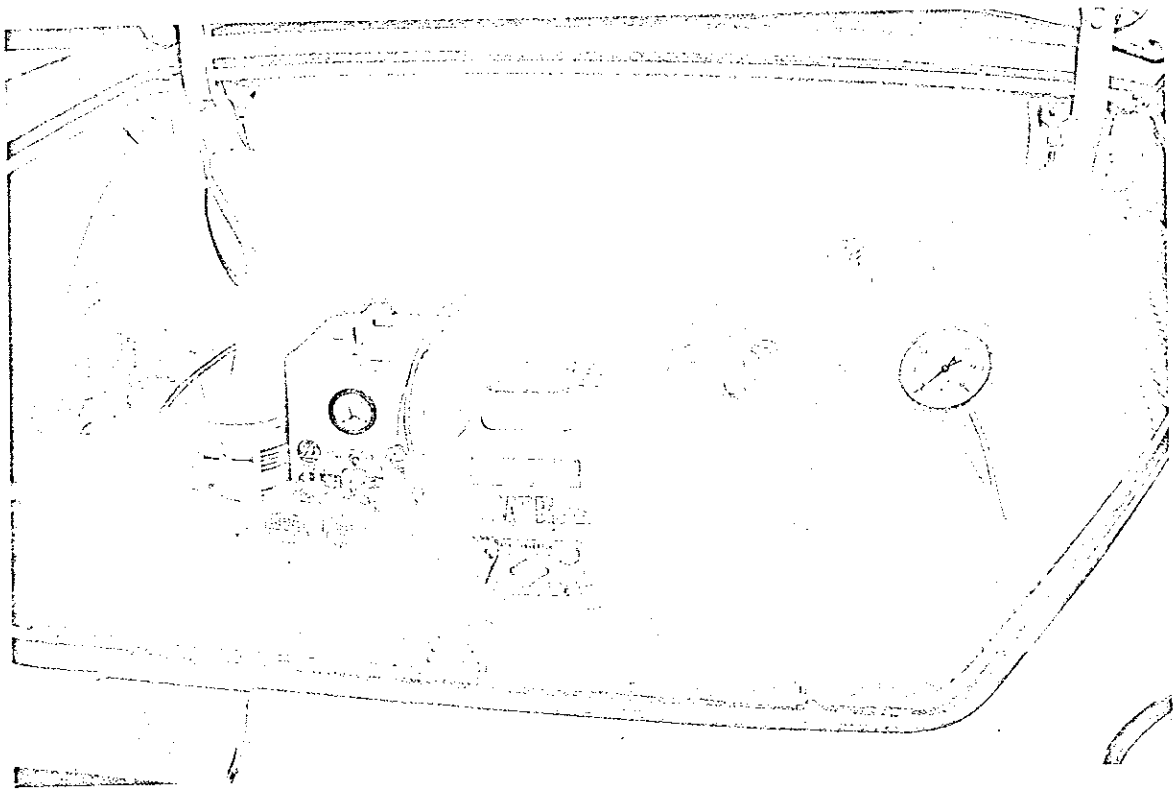
Development of the mechanical dummy was finally abandoned as not being a practical approach.

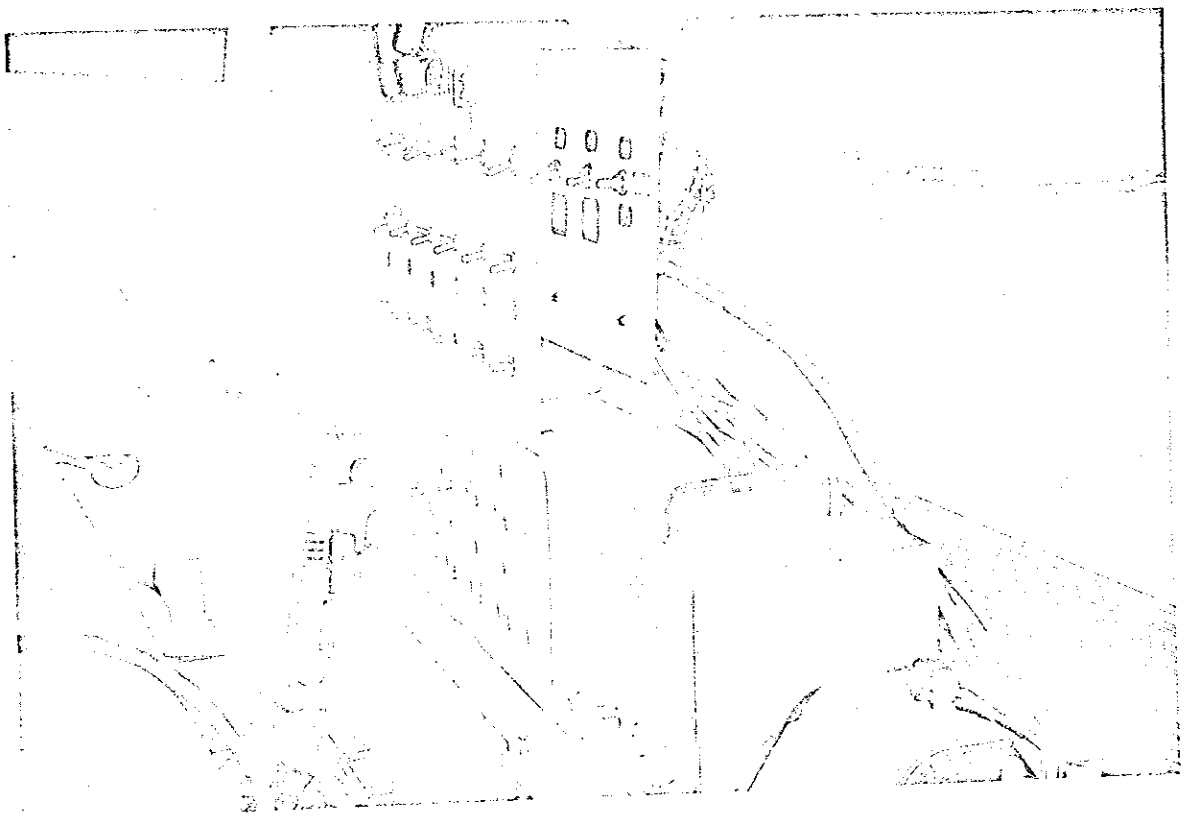
The most promising approach appears to be the differential motions between the car chassis and the wheel. These recordings most nearly match the profilograph records.

Acknowledgements

Acknowledgement is given to the following individuals who participated in this study: F. N. Hveem, J. L. Beaton, J. E. Barton, L. S. Hannibal, A. Sequeira, C. Jung, L. Bourget, M. Wilson, L. Luzier, G. B. Sherman, G. Sedrakian, J. Eagan, J. Hauf, M. Wilcox, L. King, A. Lyon, and F. Penrose.

FIGURE 1





HEALDSBURG FREEWAY - JUL. 25
ACCELEROMETER LOCATIONS
'58 CHEVROLET SEDAN

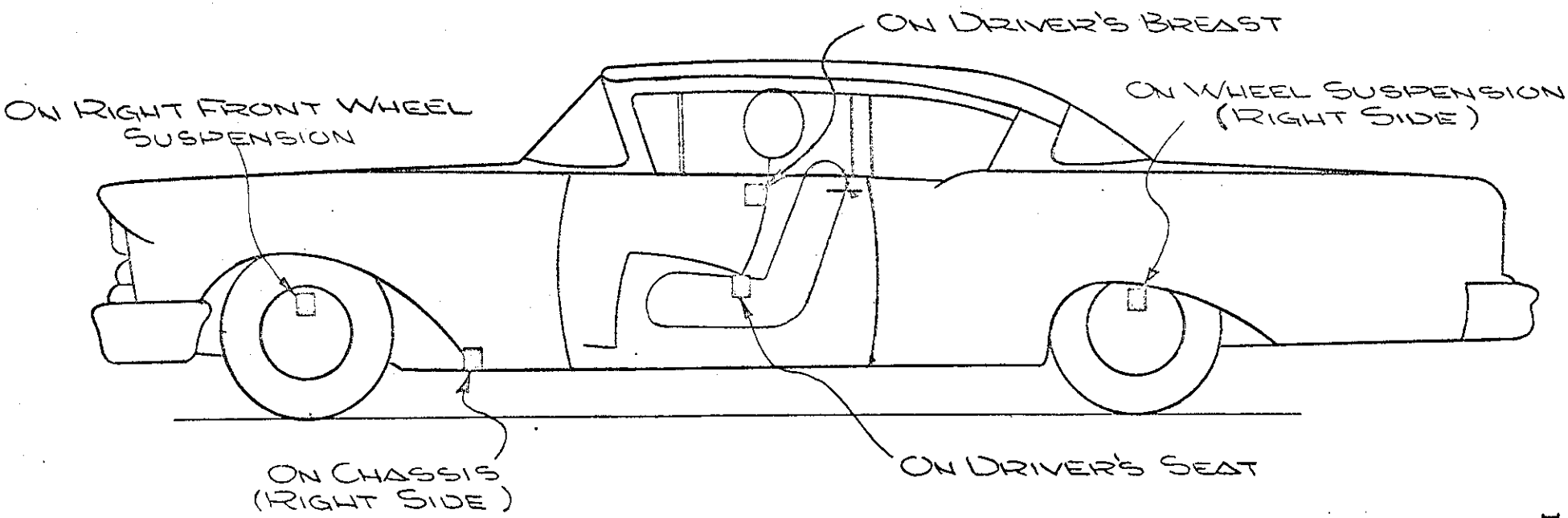


FIGURE 2

RUN # 112 ~ LOCATION: WINTERS, NORTH BOUND, OUTSIDE LANE ~ SPEED: 55 MPH ~ ACCELEROMETER ON RT. FRONT WHEEL ~ FREQ. = 13.5 CY/SEC.

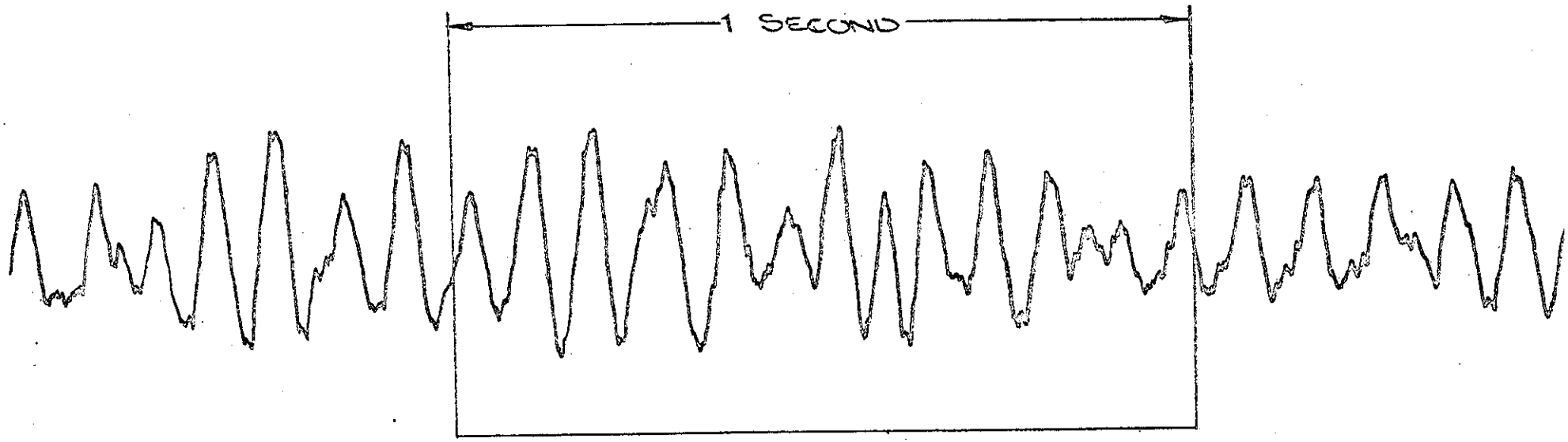
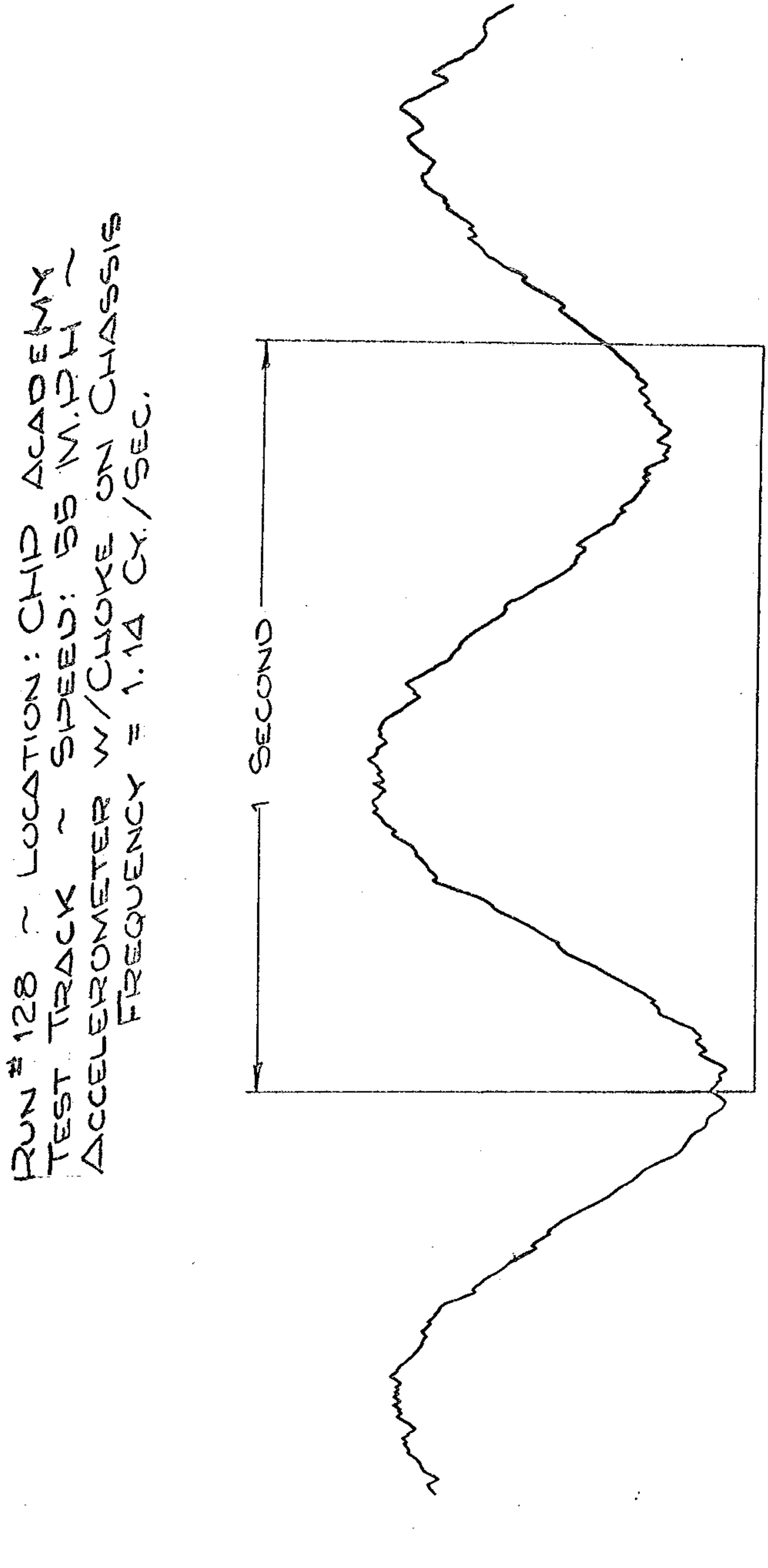


FIGURE 3

FIGURE 4


RUN # 128 ~ LOCATION: CHP ACADEMY
TEST TRACK ~ SPEED: 55 M.P.H ~
ACCELEROMETER W/CHOKE ON CHASSIS
FREQUENCY = 1.14 CY./SEC.
1 SECOND

RUN # 146 ~ LOCATION: ROSEVILLE, WEST BOUND, OUTSIDE LANE ~ SPEED: 35 MPH ~ ACCELEROMETER ON RIGHT FRONT WHEEL SUSPENSION.

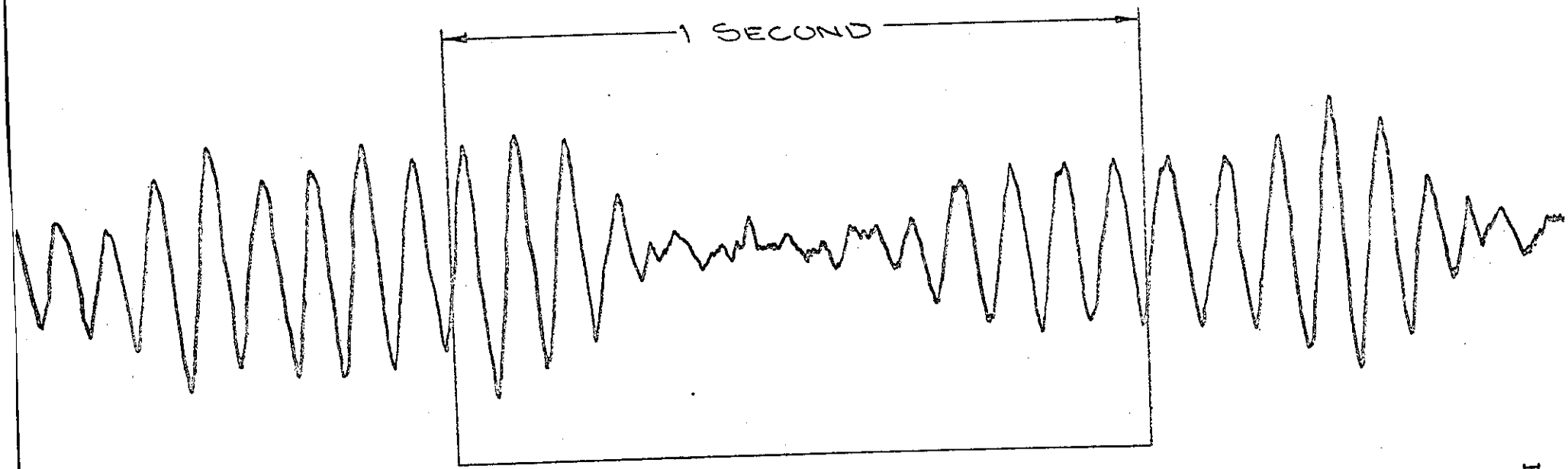
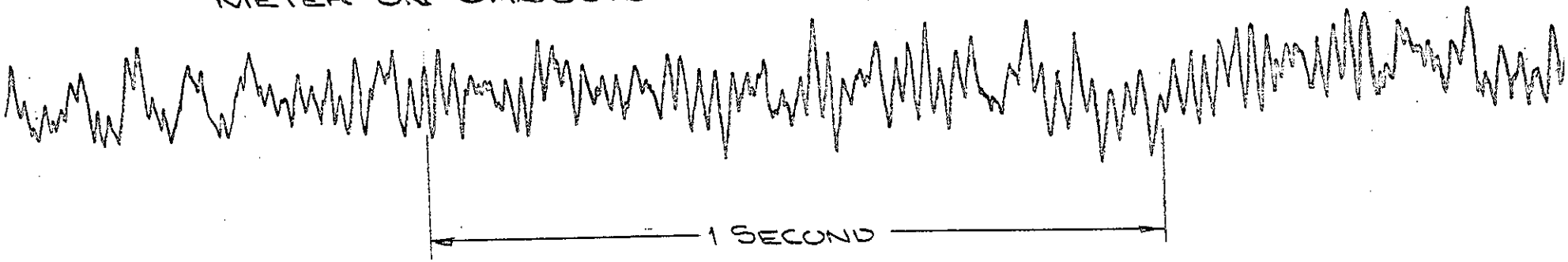
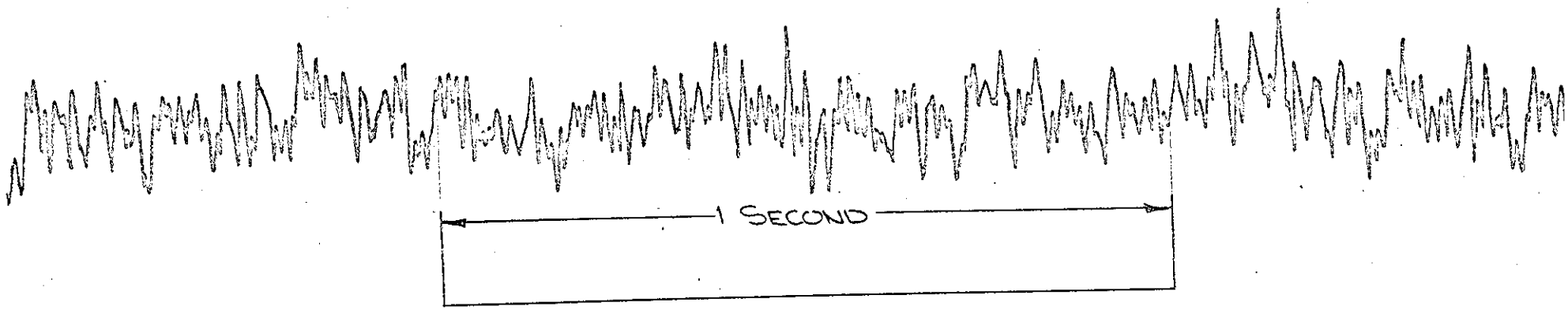


FIGURE 5

RUN #160 ~ LOCATION: ROSEVILLE, WEST BOUND, OUTSIDE LANE ~ SPEED: 35 MPH ~ ACCELEROMETER ON CHASSIS ~ FREQUENCY = 50 CY./SEC.

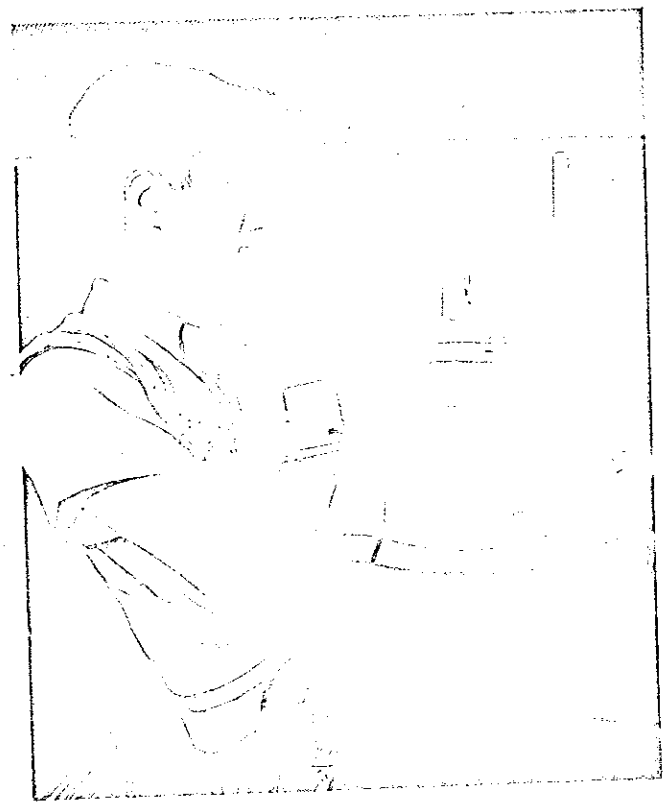




RUN #80 ~ LOCATION: DIXON, EAST BOUND, OUTSIDE LANE ~ SPEED: 55 MPH ~ ACCELEROMETER ON CHASSIS ~ FREQUENCY = 75 CY./SEC.

FIGURE 6

FIGURE 7



Accelerometer mounted on the chest.

FIGURE 8

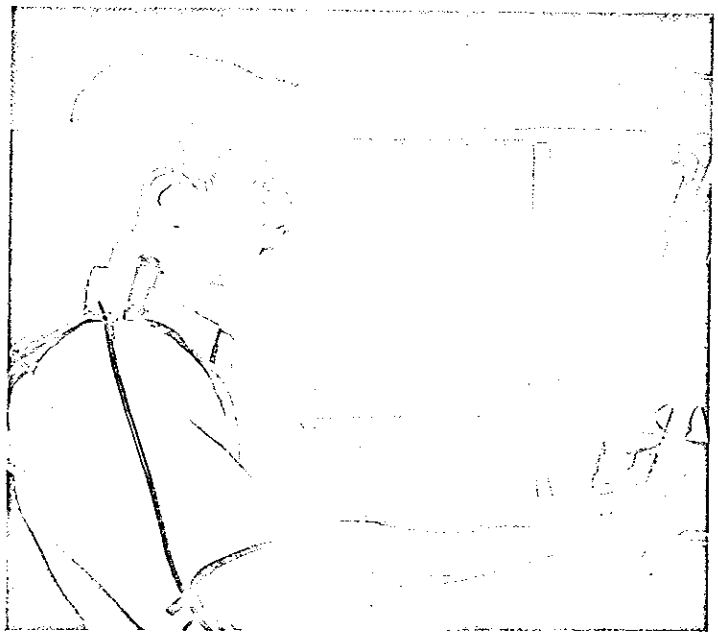


FIGURE 9

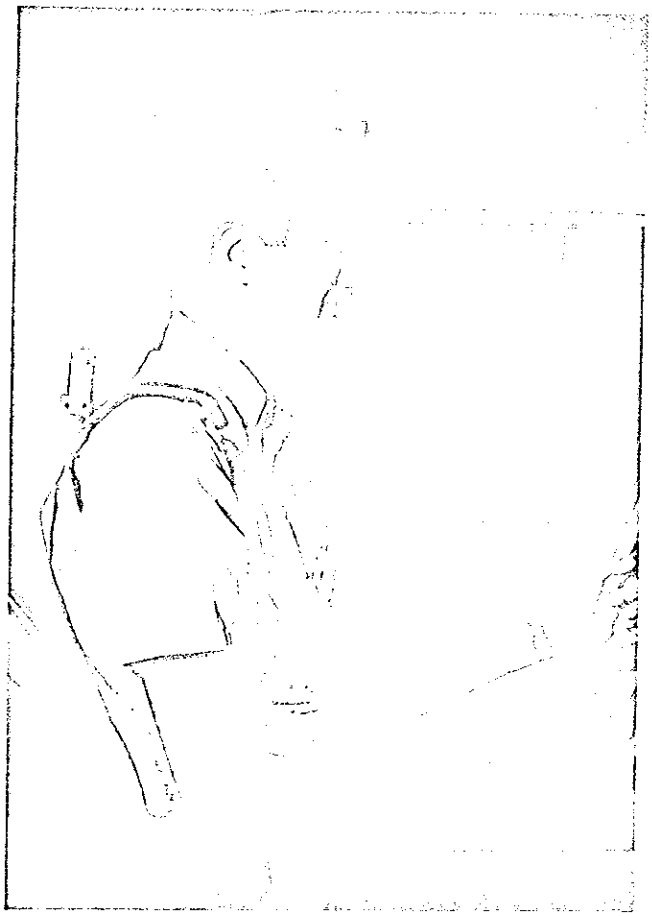
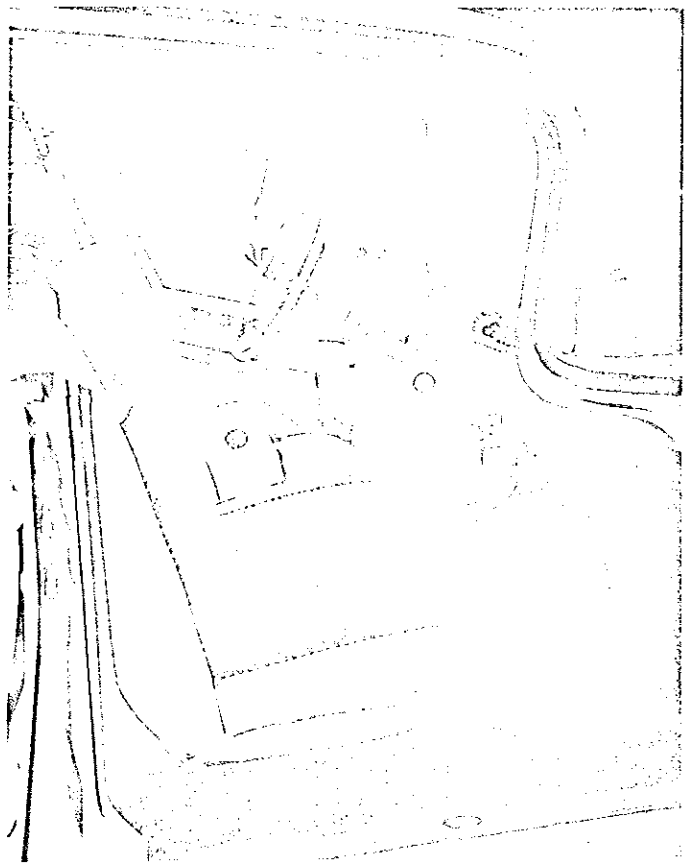


FIGURE 10



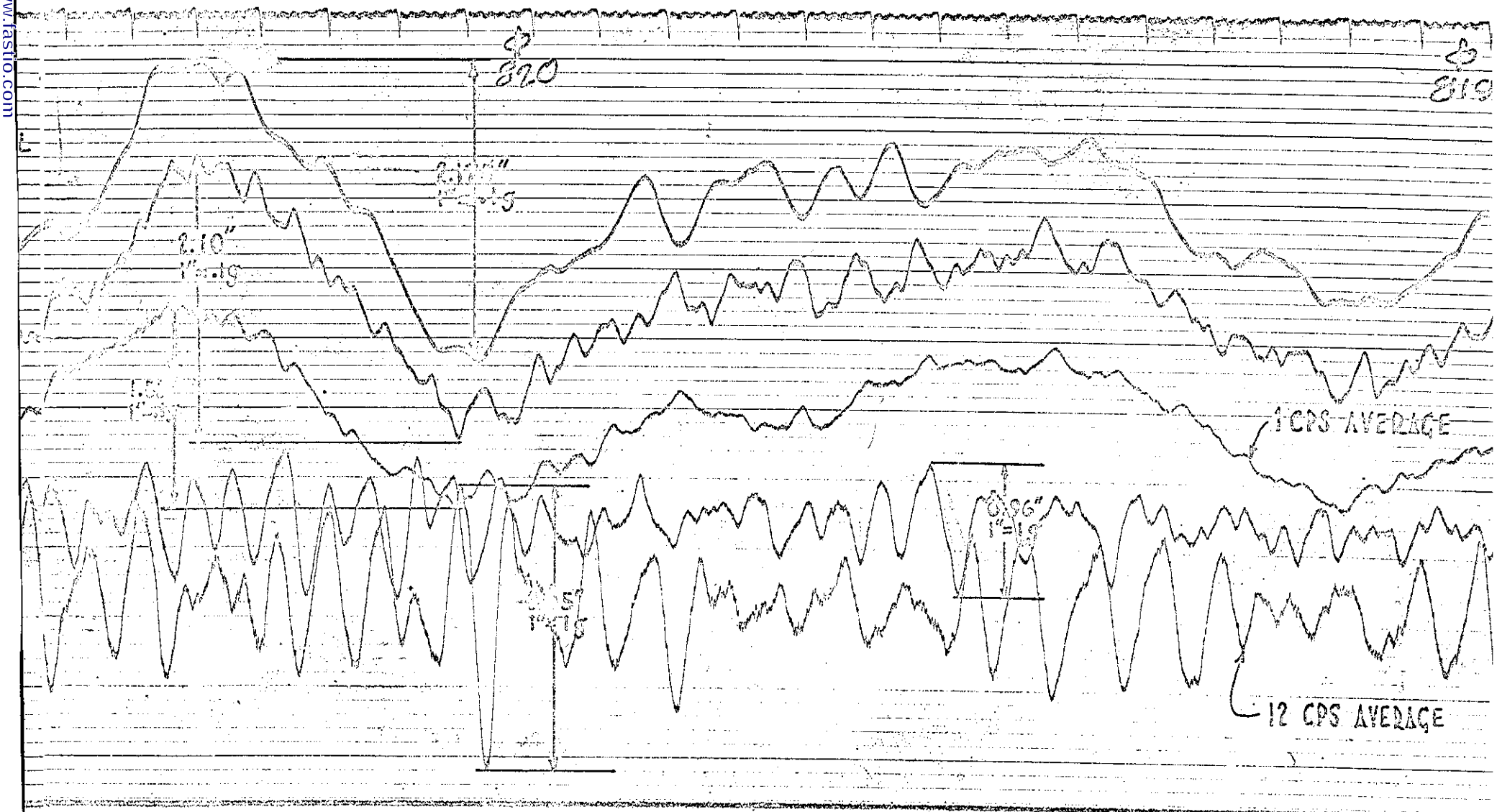
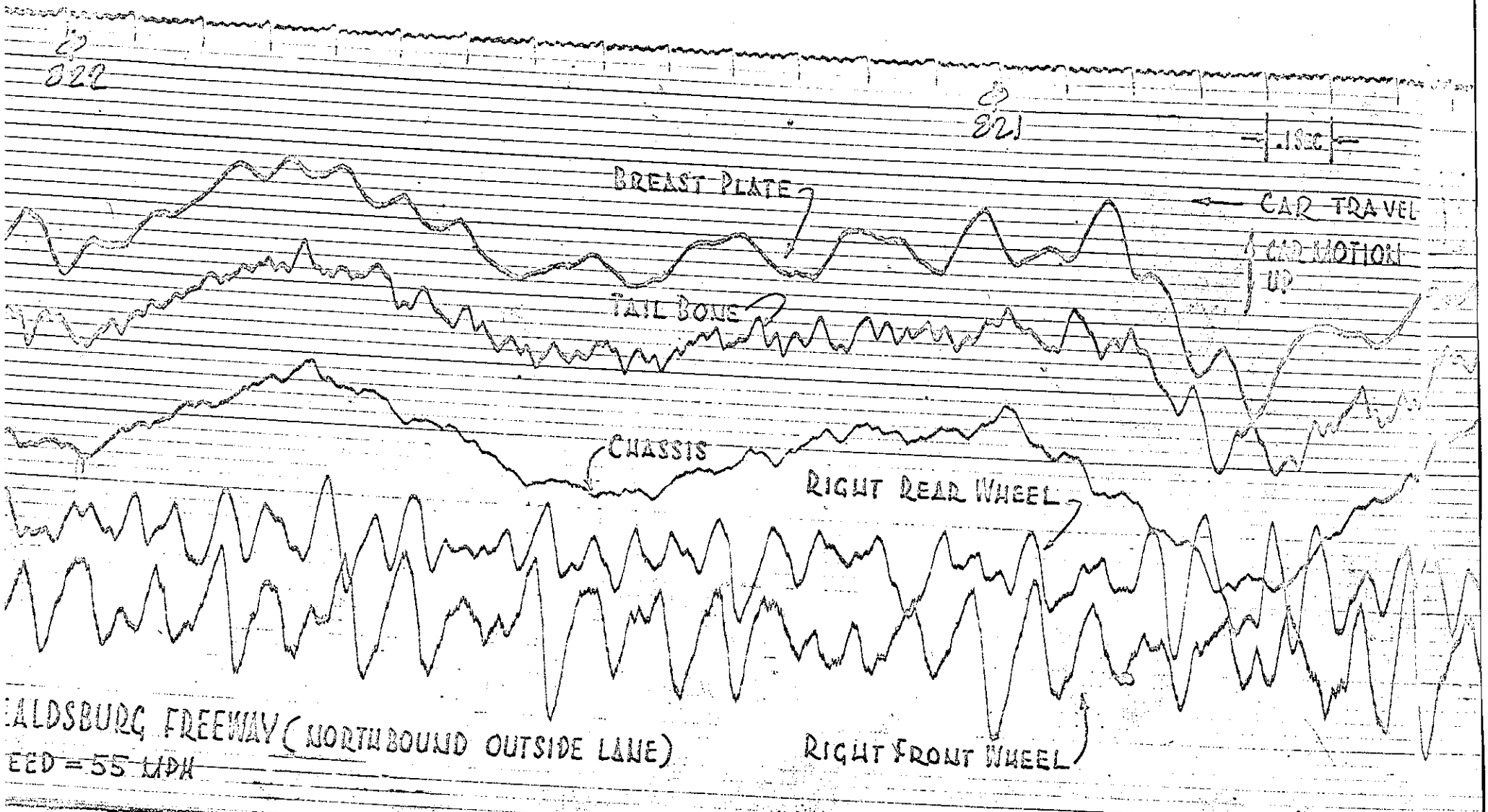

820
810
2.10"
1"=.1S
2.10"
1"=.1S
1.56"
1"=.1S
1.5"
1"=.1S
0.96"
1"=.1S
1 CPS AVERAGE
12 CPS AVERAGE

FIGURE 11



ALDSBURG FREEWAY (NORTHBOUND OUTSIDE LANE)

EED = 55 MPH

FIGURE 11A

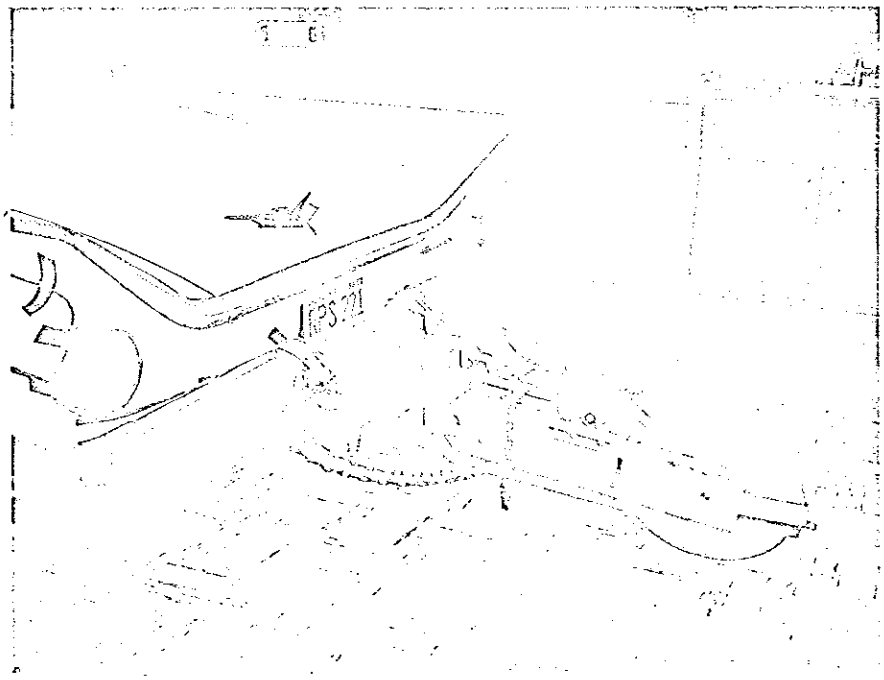


FIGURE 12

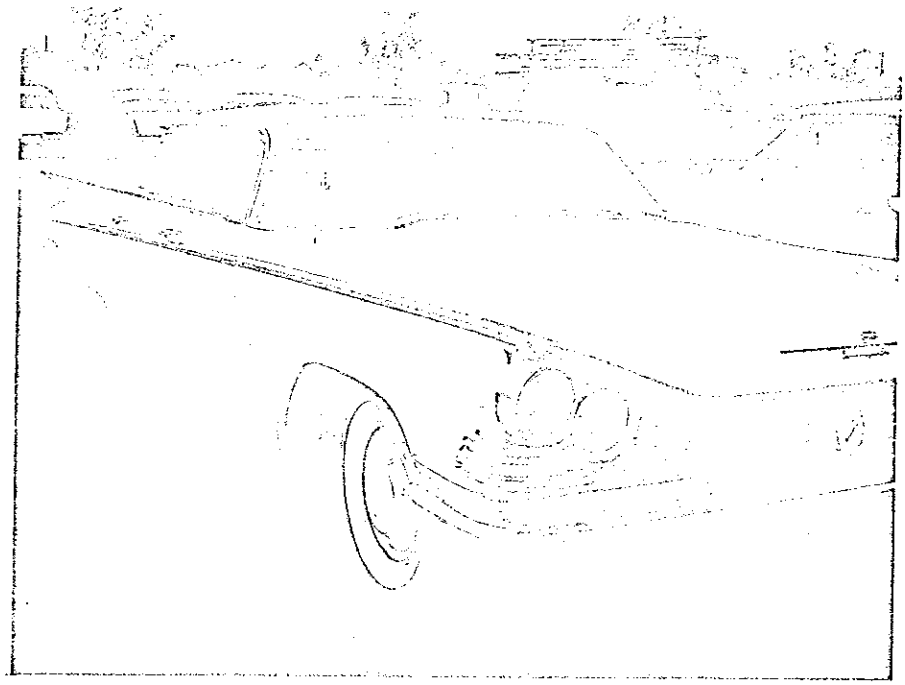


FIGURE 13

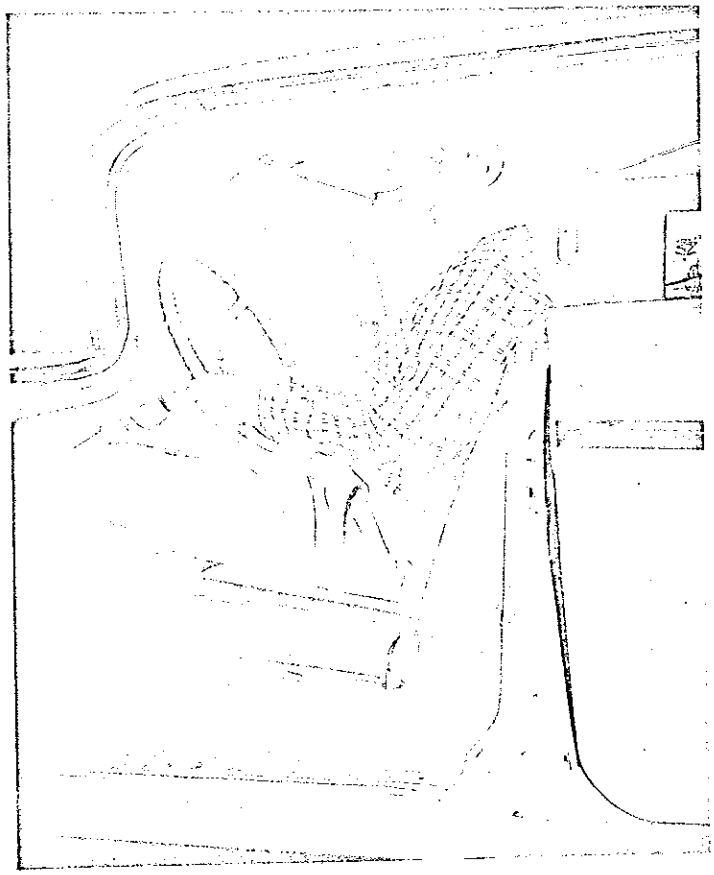
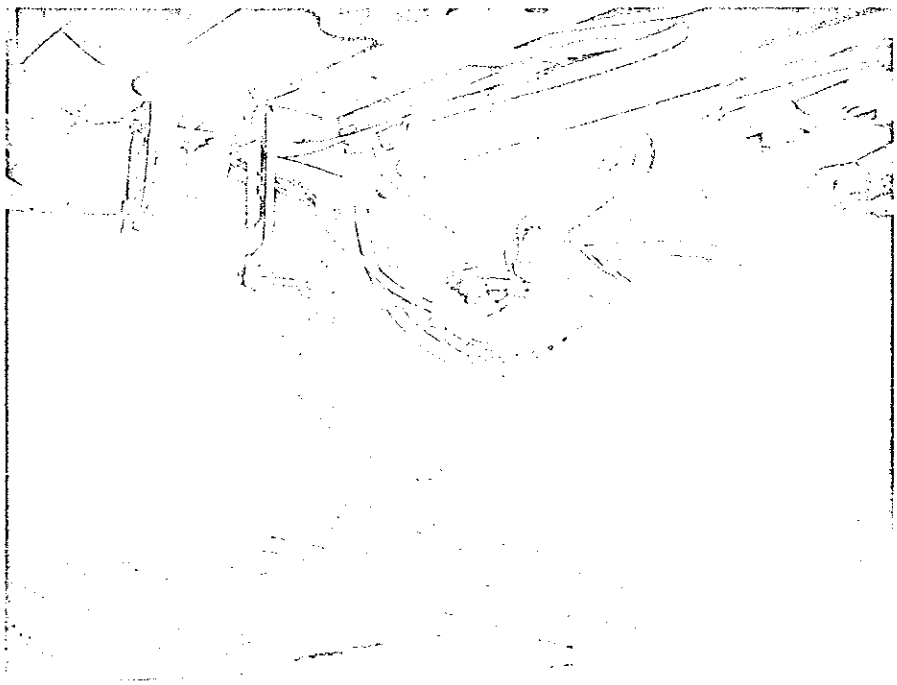


FIGURE 14



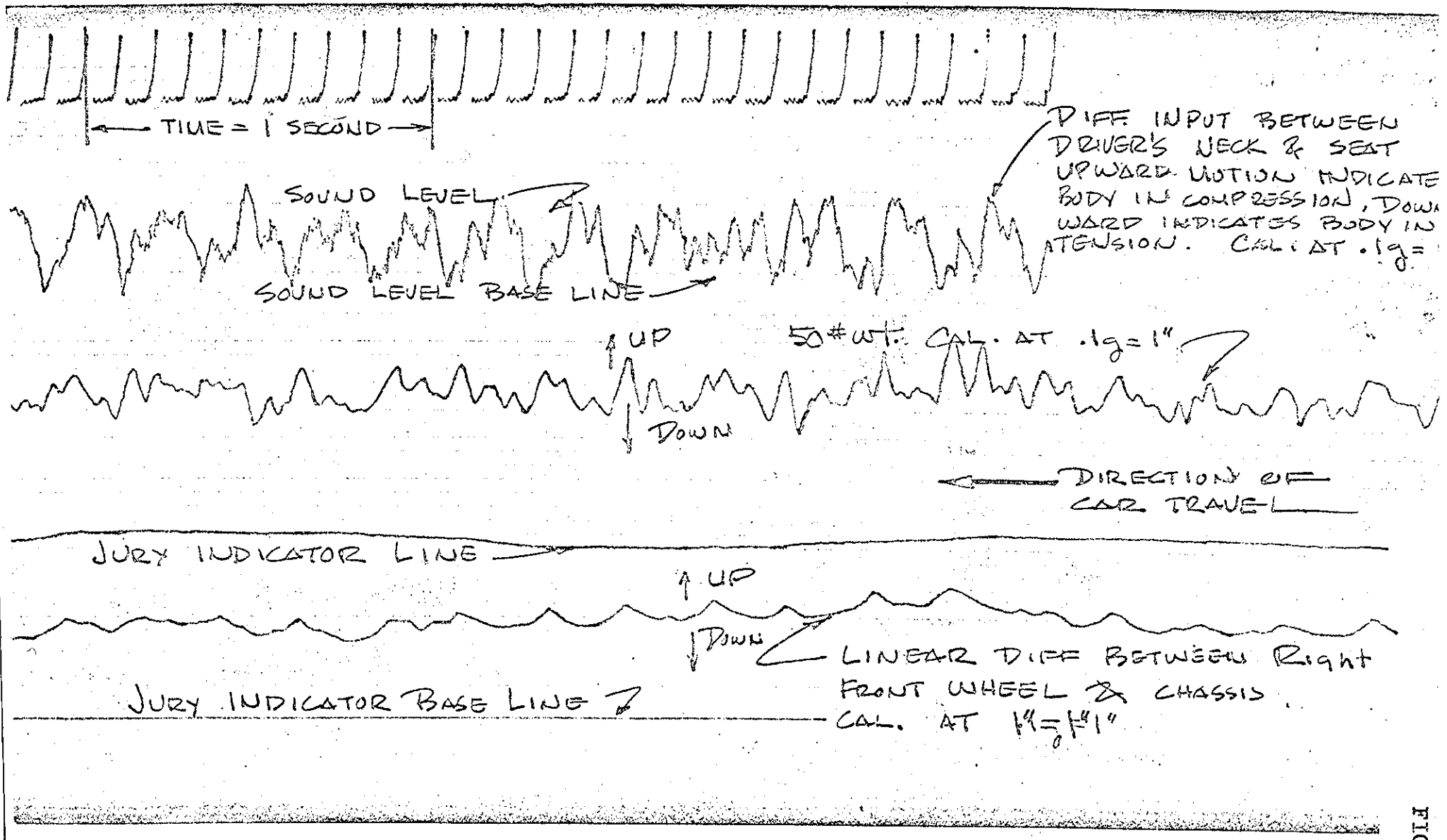
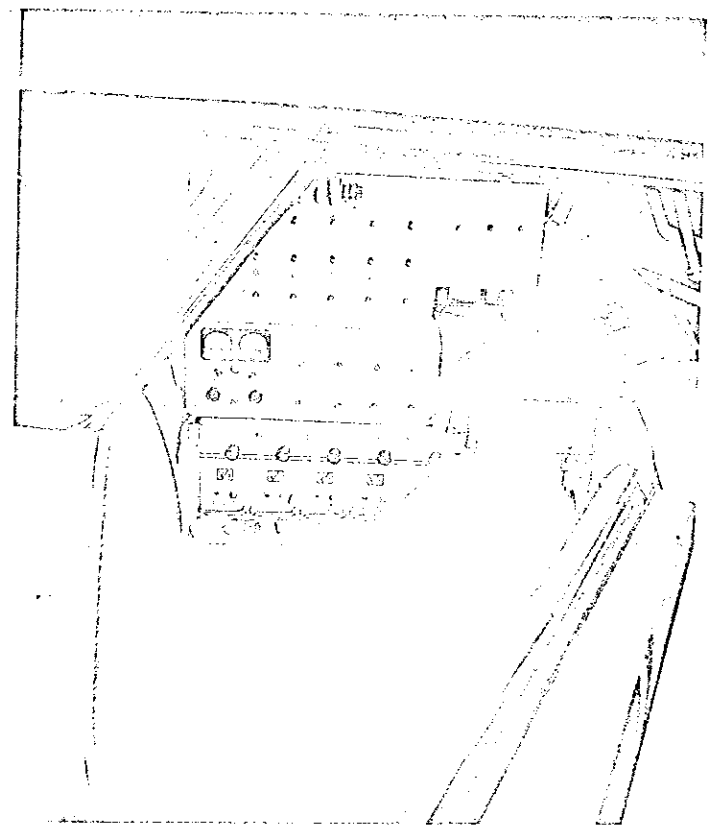
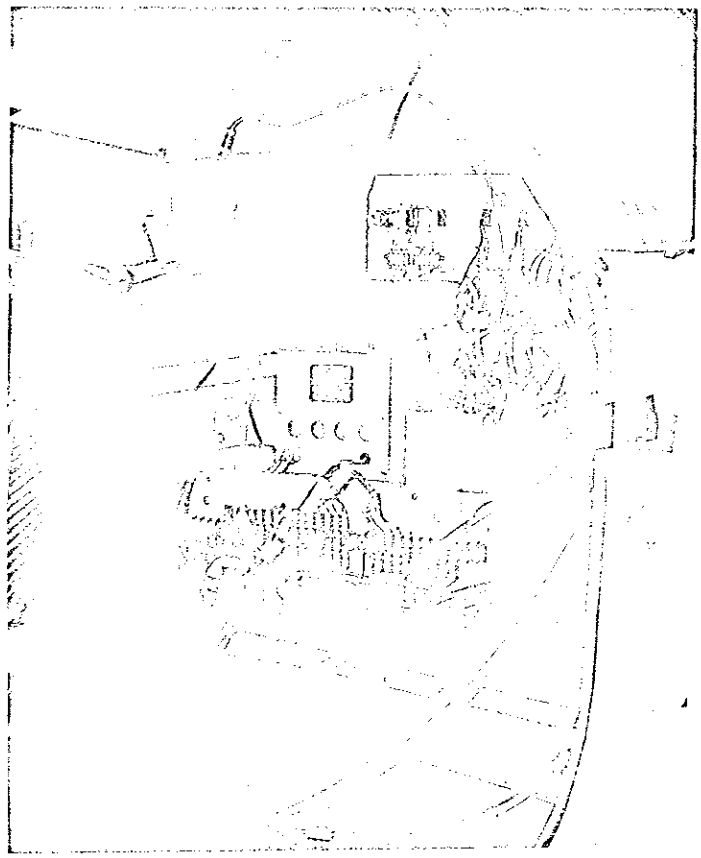

TIME = 1 SECOND
DIFF INPUT BETWEEN DRIVER'S NECK & SEAT UPWARD MOTION INDICATE BODY IN COMPRESSION, DOWNWARD INDICATES BODY IN TENSION. CAL. AT .1g=
SOUND LEVEL
SOUND LEVEL BASE LINE
UP
DOWN
50# wt. CAL. AT .1g=1"
DIRECTION OF CAR TRAVEL
JURY INDICATOR LINE
UP
DOWN
LINEAR DIFF BETWEEN Right FRONT WHEEL & CHASSIS. CAL. AT 1"=1"
JURY INDICATOR BASE LINE

FIGURE 15

FIGURE 16





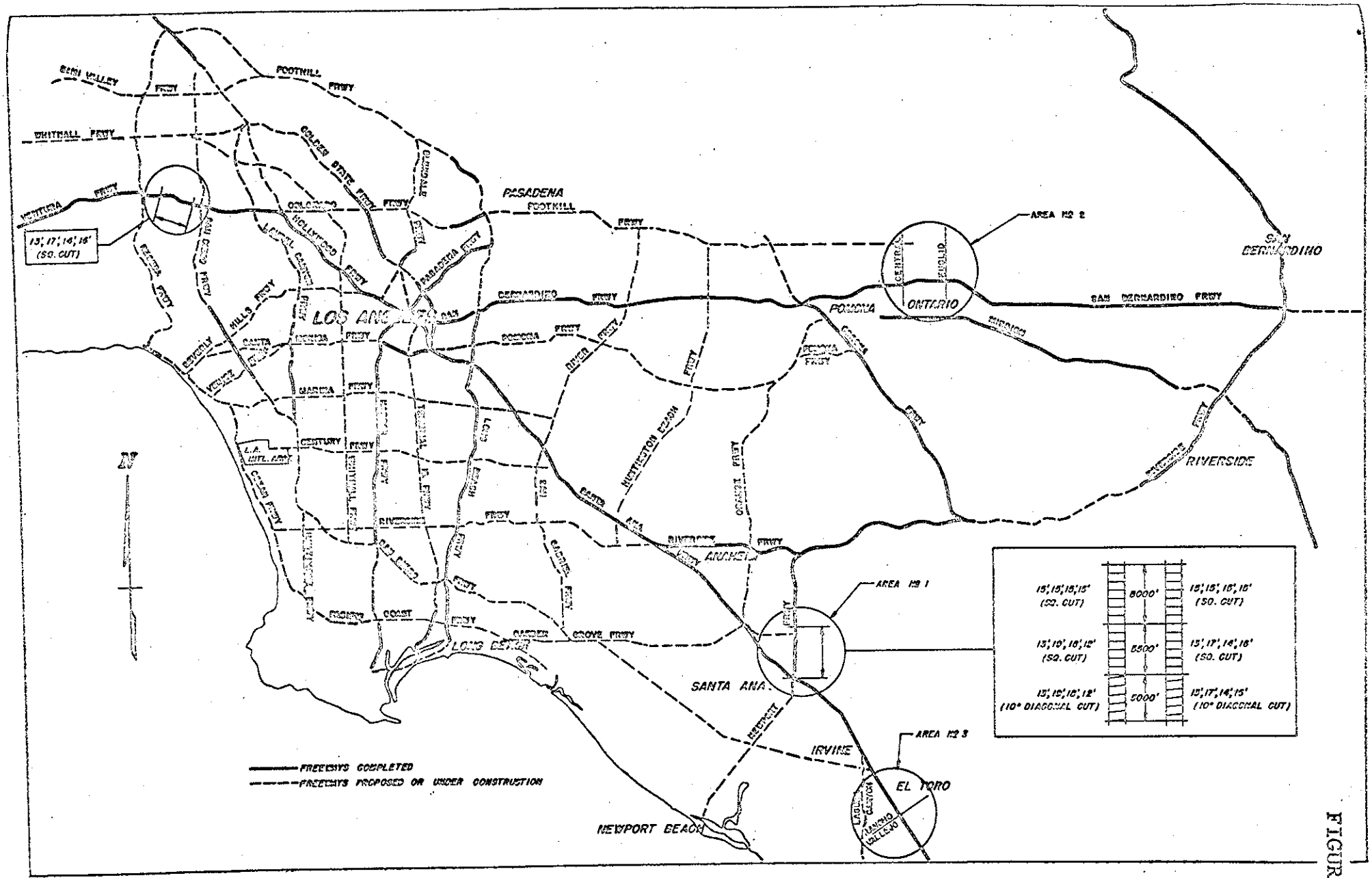

FOOTHILL FWY
SAN BERNARDINO FWY
PASADENA FOOTHILL FWY
POMONA
ONTARIO
RIVERSIDE
LOS ANGELES
SANTA ANA
IRVINE
EL TORO
NEWPORT BEACH
LONG BEACH
AREA NO 2
AREA NO 1
AREA NO 3
13',17',16',16' (SQ. CUT)
15',15',15',15' (SQ. CUT)
15',15',16',16' (SQ. CUT)
8000'
13',19',16',12' (SQ. CUT)
15',17',14',16' (SQ. CUT)
5500'
13',15',16',12' (10° DIAGONAL CUT)
15',17',14',15' (10° DIAGONAL CUT)
5000'
N
FREEWAYS COMPLETED
FREEWAYS PROPOSED OR UNDER CONSTRUCTION

FIGURE 17

FIGURE 18

	Pronounced Hop	No Hop	Run No.
Long Beach Freeway			
Spare Tire in Trunk	X		289 & 290
Spare Tire Out		X	287 & 288
Harbor Freeway			
Fifth Wheel & Spare Tire in Trunk	X		299 & 300
Fifth Wheel Out		X	295 & 296
Ventura Freeway			
Fifth Wheel & Spare Tire in Trunk		X	301 & 302
Fifth Wheel Out	X		303 & 304

Matching Runs With 1959 and 1961 Buick

Alameda Street	292 & 319 SBIL
Harbor Freeway	295 & 323 NB 3rd Lane
Harbor Freeway	296 & 324 SB 3rd Lane
Ventura Freeway	303 & 312 LA Bound 2nd Lane
Ventura Freeway	304 & 313 Ventura Bound 2nd Lane
Long Beach Freeway	287, 290 & 318 SBIL

HOP TEST

Runs made in Los Angeles

1959 Buick

Run No.	Speed	Location
287	54	Long Beach Freeway SBIL Spare Tire Out
288	60	Long Beach Freeway SBIL Spare Tire Out
289	60	Long Beach Freeway SBIL Spare Tire in Trunk
290	54	Long Beach Freeway SBIL Spare Tire in Trunk
292	55	Alameda Street SBIL
295	54	Harbor Freeway NB 3rd Lane
296	54	Harbor Freeway SB 3rd Lane
299	54	Harbor Freeway NB 3rd Lane Fifth Wheel in Trunk
300	54	Harbor Freeway SB 3rd Lane Fifth Wheel in Trunk
301	54	Ventura Freeway LA Bound 2nd Lane Fifth Wheel in Trunk
302	54	Ventura Freeway Ventura Bound 2nd Lane Wheel in Trunk
303	54	Ventura Freeway LA Bound 2nd Lane
304	54	Ventura Freeway Ventura Bound 2nd Lane

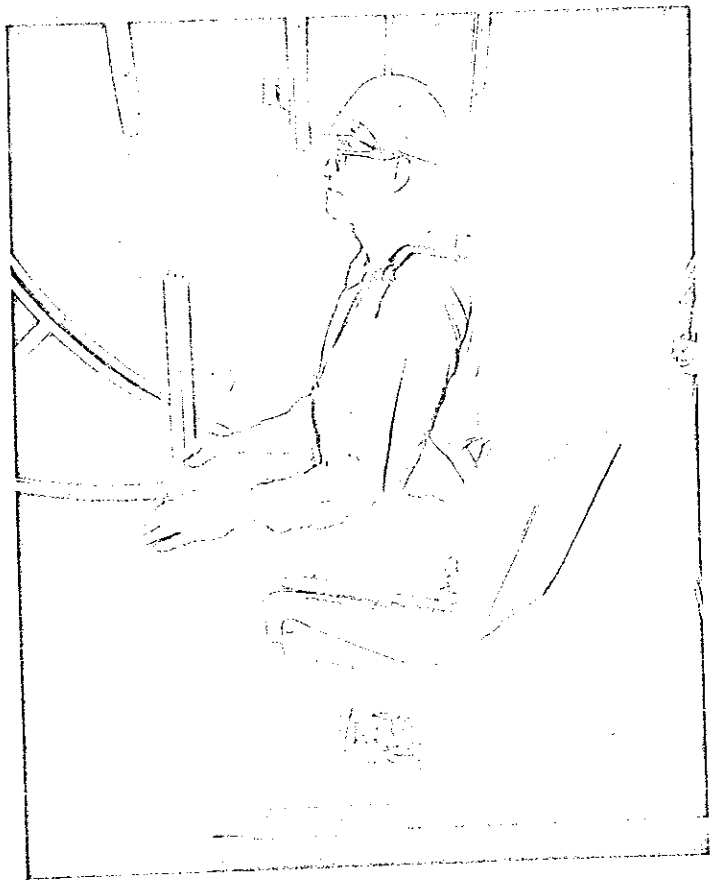
1961 Buick

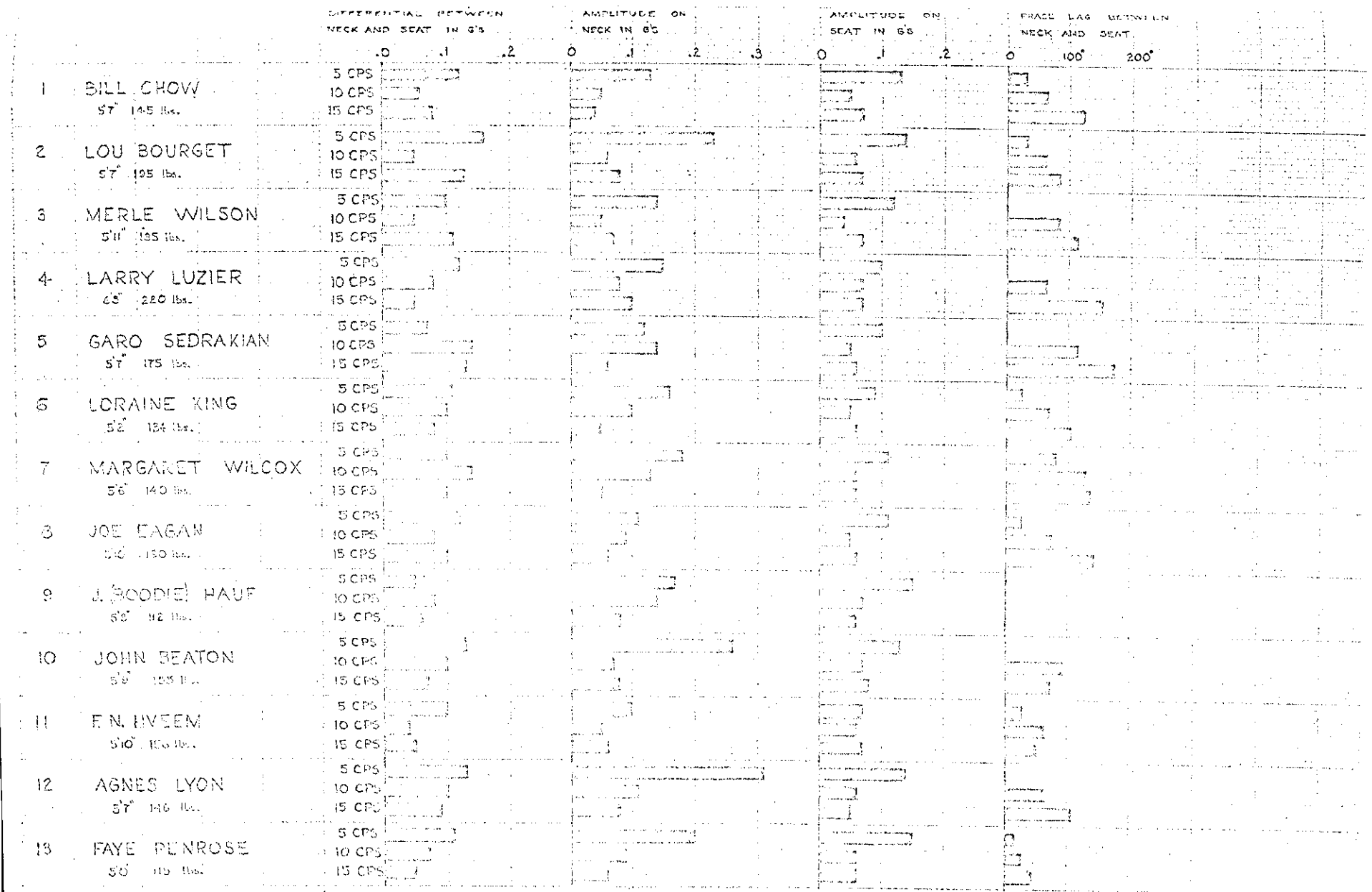
312	54	Ventura Freeway LA Bound 2nd Lane
313	54	Ventura Freeway Ventura Bound 2nd Lane
318	54	Long Beach Freeway SBIL
319	55	Alameda Street SBIL
323	54	Harbor Freeway NB 3rd Lane
324	54	Harbor Freeway NB 3rd Lane

Where beats occurred and where recorded on 1959 Buick.

299	54	Harbor Freeway NB 3rd Lane Fifth Wheel in Trunk
288	60	Long Beach Freeway SBIL Spare Tire Out
263	50	Antioch WBIL Spare Tire in Trunk
265	55	Antioch WBIL Spare Tire in Trunk
300	54	Harbor Freeway SB 3rd Lane Fifth Wheel in Trunk

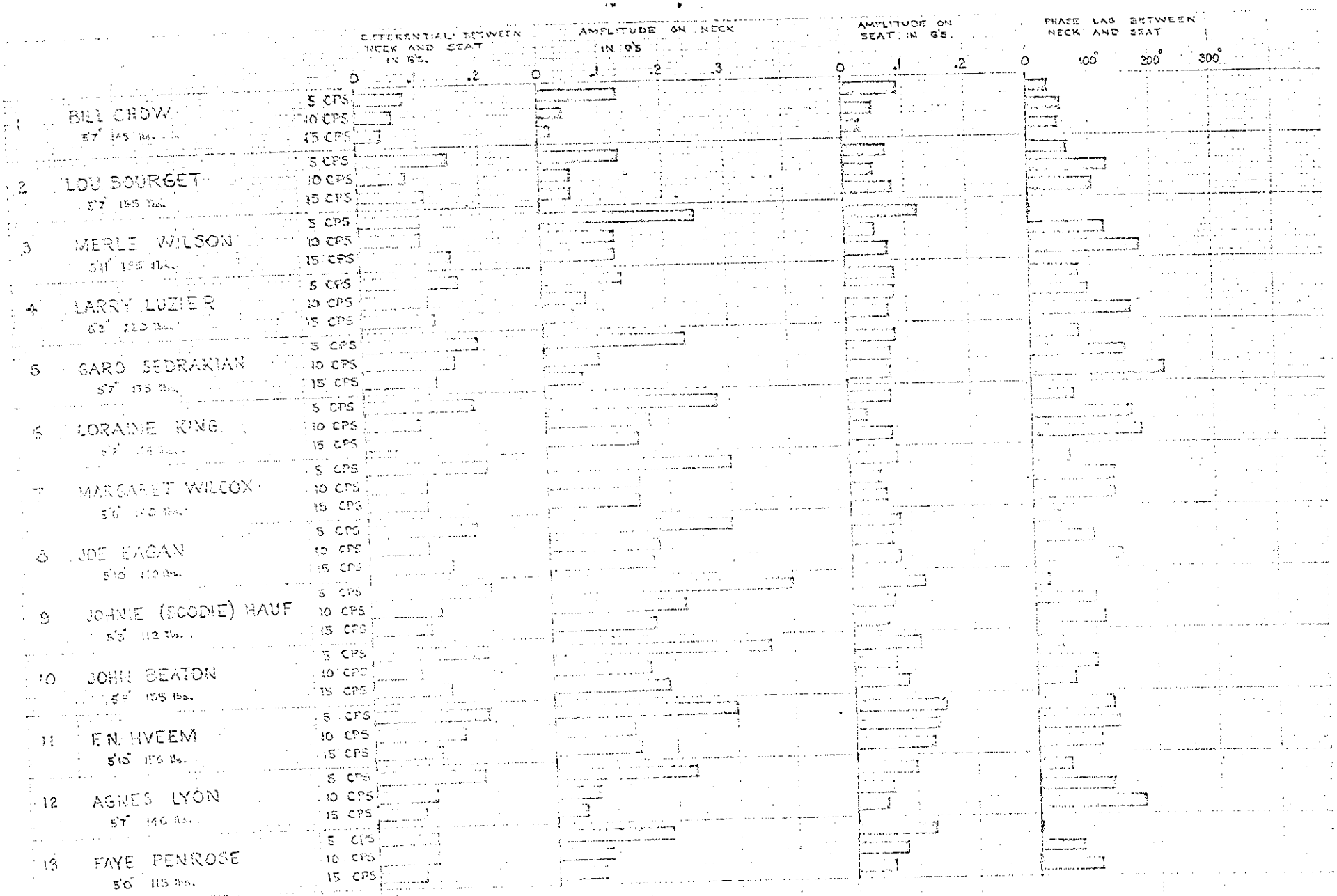
FIGURE 20





SUBJECTIVE RESPONSE
ON
SHAKE TABLE
— SITTING BACK —

FIGURE 20A

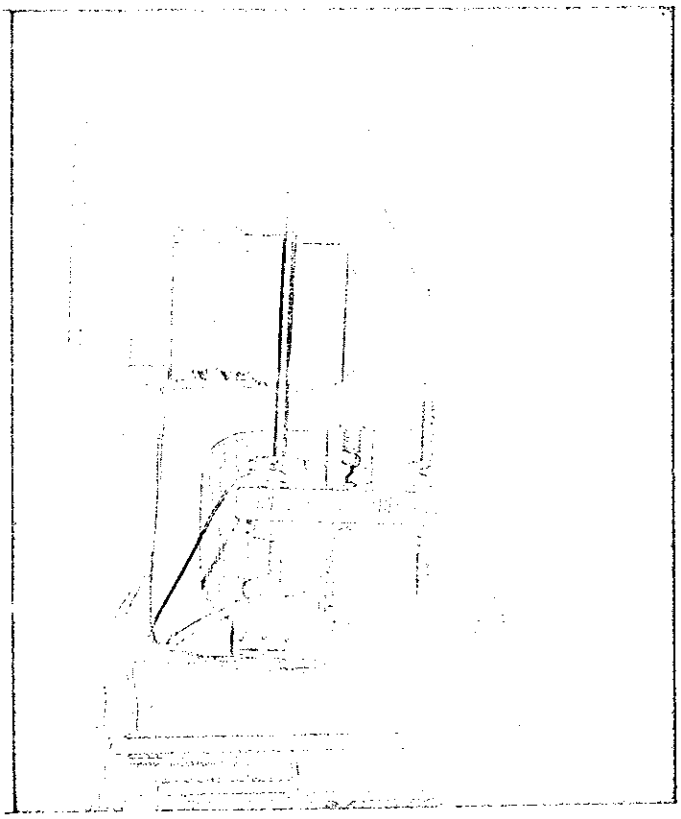


SUBJECTIVE RESPONSE ON SHAKE TABLE

— SITTING UPRIGHT —

FIGURE 20B

FIGURE 21



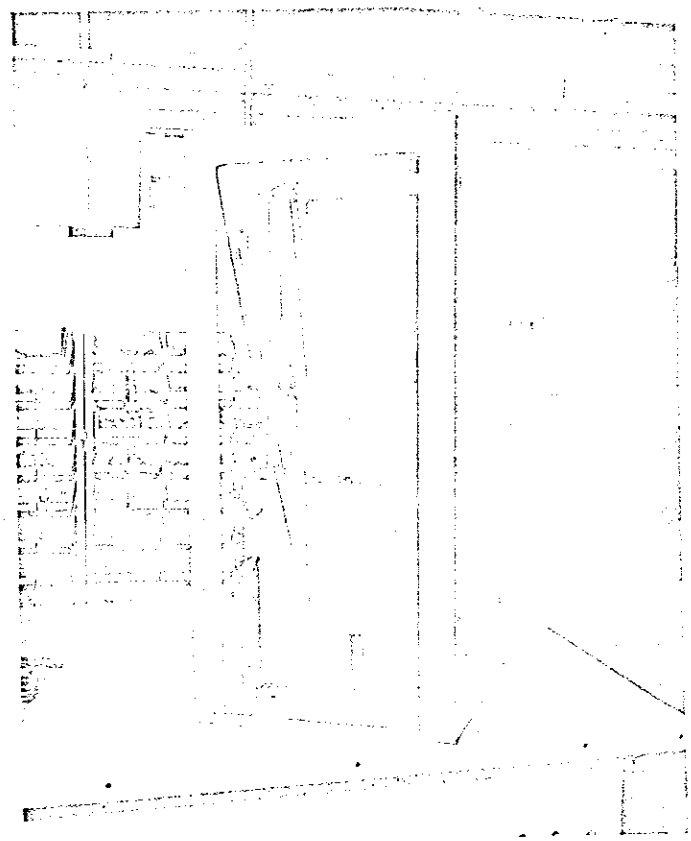
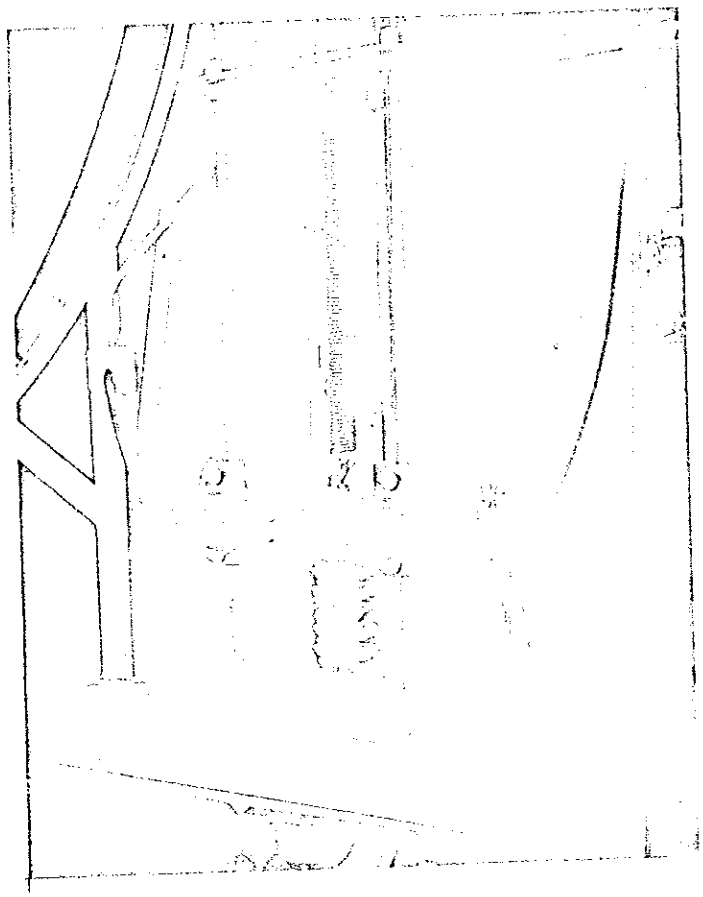
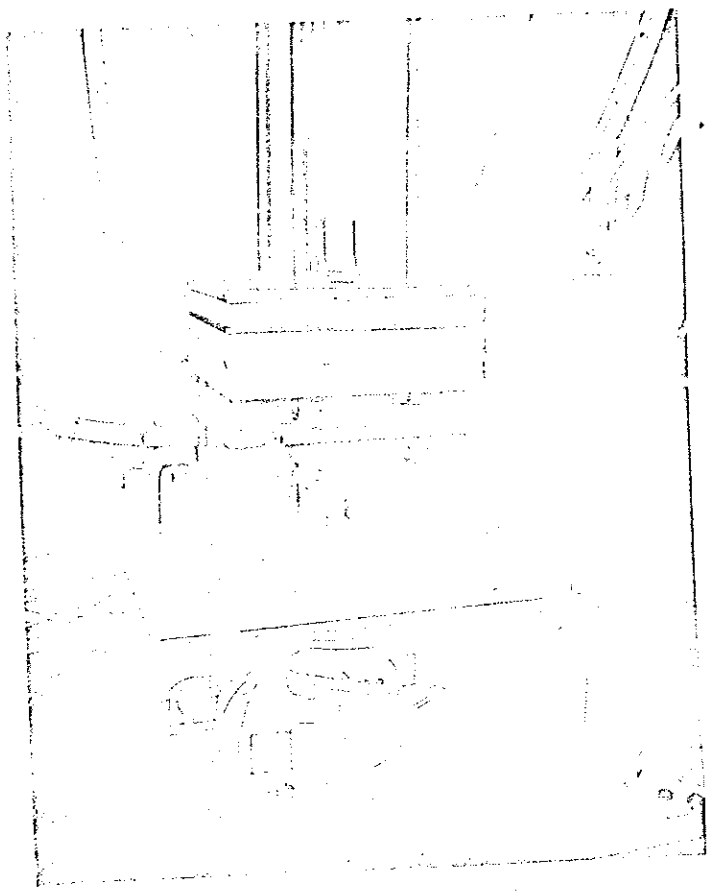
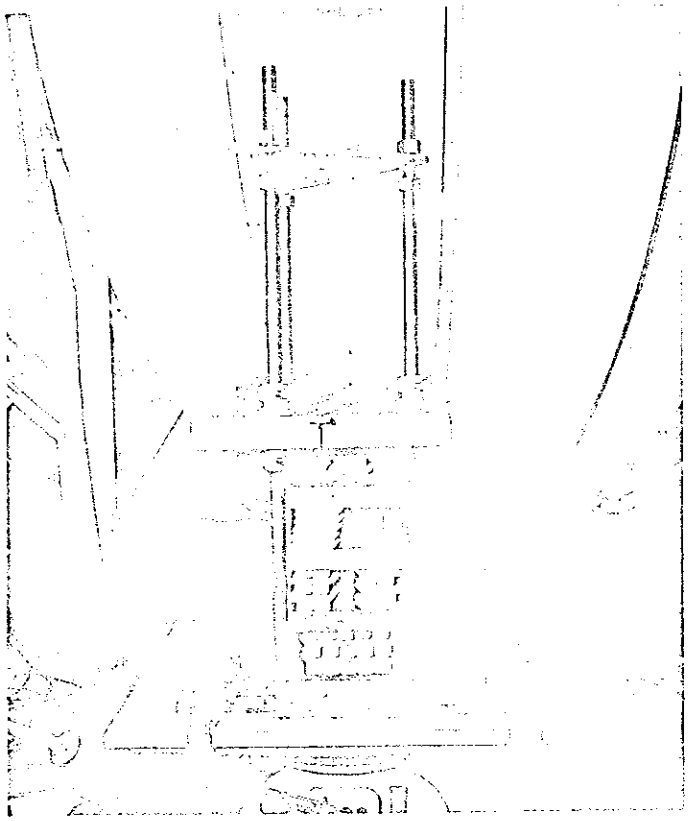


FIGURE 22







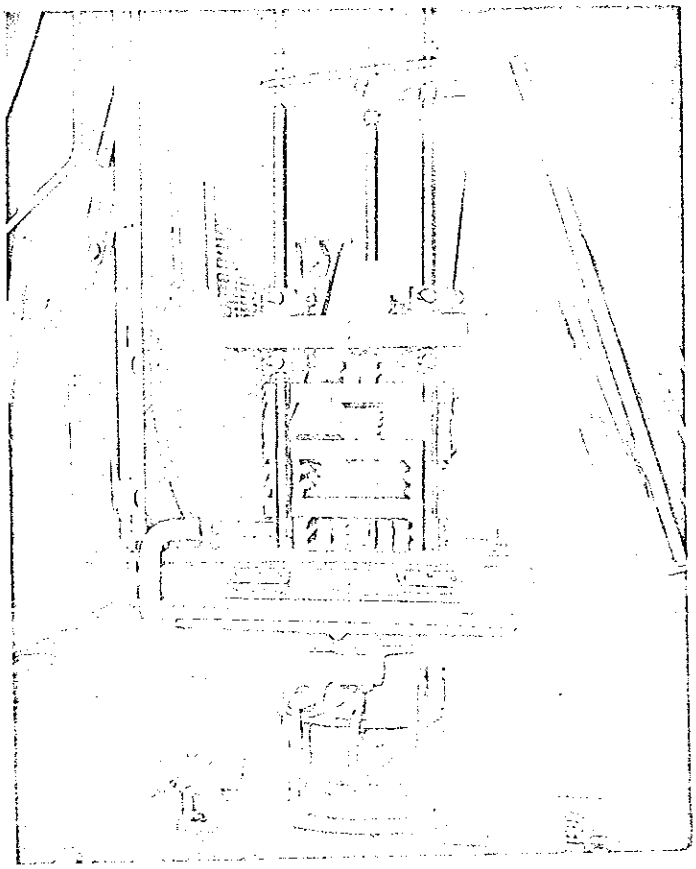
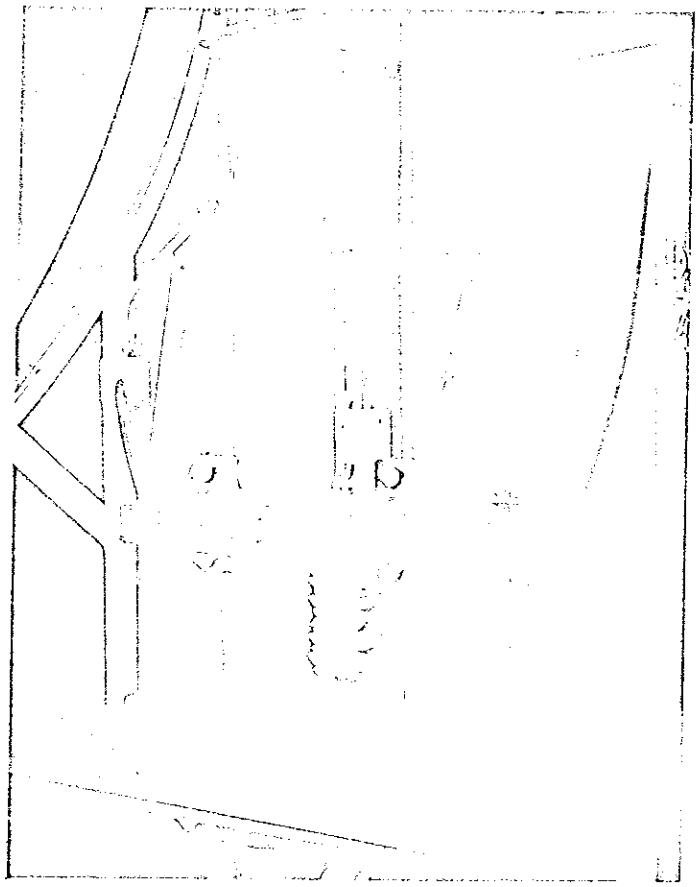


FIGURE 24



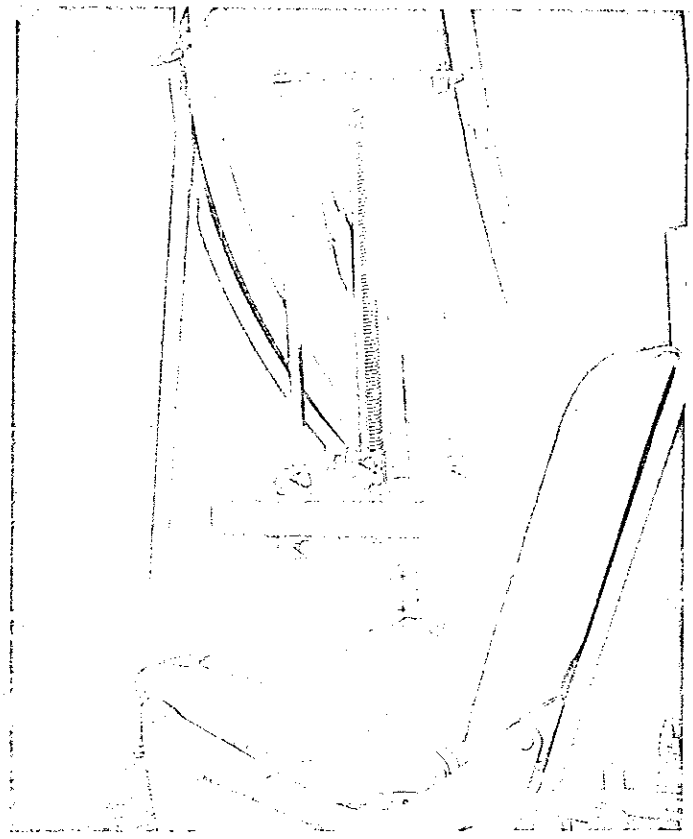


FIGURE 25